CHAPTER 28

LIGHTNING PROTECTION

28-1. General lightning protection systems

Lightning protection is essential for the protection of humans, structures, contents within structures, transmission lines, and electrical equipment from thermal, mechanical, and electrical effects caused by lightning discharges. Lightning cannot be prevented, but it can with some success be intercepted, and its current can be conducted to a grounding system without side flashes where it is harmlessly dissipated.

28-2. Lightning effects on power systems

Lightning surges entering a power system through direct strokes are the primary concern in planning surge protection. These strokes may hit phase conductors directly, or they may strike the overhead ground wires or masts that shield the conductors. In either case, it is necessary to understand the associated surge currents and voltages produced before a protection system can be designed.

a. Flashover. A lightning stroke terminating directly on phase conductors or equipment terminals develops a very high voltage, which, with no surge protection, will flash over the insulation in the majority of cases. If the flashover occurs through air or across porcelain insulation, it rarely causes permanent damage. If, on the other hand, the flashover occurs through solid insulation such as in a transformer or cable, permanent damage results.

b. Shielding. The magnitude of surge voltages applied to equipment and line insulation systems can be limited by providing grounding masts or ground wires to intercept direct strokes. Even with a shielding network, though, there is some chance of flashover, depending on stroke current magnitude, impedance of the shielding system, and the amount of insulation between the network and the energized circuits.

c. Induced surges. A lightning stroke terminating near a transmission line can induce a voltage in the circuit that seldom exceeds 500 kV. Lines, shielded with overhead ground wires and operating at 69 kV and above, generally have sufficient insulation to prevent flashover by voltages in this range. The same applies to some well insulated 34.5 kV lines. Lower voltage lines, however, with insulation levels appreciably below 500 kV, may be flashed over by induced surges. In most cases, these circuits do not have ground wires, and are, therefore, subject to flashover each time they are contacted by a direct stroke. In general, flashovers by induced surges do not create a significant problem since the number of flashovers from direct strokes far exceeds those from induced strokes.

d. Traveling waves. A lightning stroke terminating on a power system initiates traveling waves that propagate within the system. To determine the resulting surge voltages and currents in various parts of the system, a traveling wave analysis is required. Simple networks with linear impedances can be analyzed manually; more complicated networks, characteristic of practical power systems, require analog or digital computer analysis.

e. Surge voltages. In protecting power systems against lightning, surge voltages and currents must be considered. In general, lightning protection is primarily concerned with surge voltages; surge currents cause less concern. A lightning stroke to a power system develops very high surge voltages across equipment and line insulation systems. If these voltages exceed the insulation strength, a flashover occurs. Once lightning enters a power system, the surge current is unlikely to cause any damage. Although the current may be extremely high, it is very short lived and can easily be handled by a small conductor. The largest recorded conductor to be fused or vaporized by a direct stroke was an American Wire Gage (AWG) No. 10. The size of conductors, installed expressly for conducting lightning currents, is usually determined by mechanical strength considerations, rather than by current-carrying capacity. On some rare occasions, overhead ground wires have been severed by lightning at the point of contact. This is probably due to the stroke channel heating the conductor at the point of impingement, rather than from simply conducting the lightning current.

28-3 Principles of protection

Main lightning protection requirements are dependent upon the structure, component, or system to be protected. According to National Fire Protection Association (NFPA) 780, Standard for Installation of Lightning Protection Systems (1997), there are two classifications for a building. Class I is a building with less than 75 feet height. The Class II building is higher than 75 feet or has a steel frame with any height.

a. Shielding. Shielding masts are commonly used in substations, and overhead ground wires are used in both substations and on transmission lines. Both use the lightning rod principle. The voltage at the top of the mast is significantly less than the 2,000 kV that would be developed for the same stroke on a conductor. Grounded masts and grounded wires, then, offer an important reduction in the magnitude of surge voltages.

b. Arresters. Even with an effective shielding system, the surge voltages must be limited to magnitudes consistent with practical and economical equipment insulation levels to allow for voltages developed by strokes to the shielding network. On rare occasions, strokes may also bypass the shielding system and terminate directly on the energized circuits. For these situations, an arrester is used to control and limit surge voltages to a safe level. The arrester, applied on or near the terminals of the protected equipment, is connected from phase to ground. Under normal operating conditions, the arrester has no effect on the power system. Under surge conditions, the arrester will spark over and conduct the surge current to ground, limiting the voltage applied to the equipment insulation to a safe level. After conducting the surge current to ground, the arrester will interrupt the power-follow current and restore itself to its normal operating conditions. There are two general types of arrester designs: valve type and expulsion type. The valve type has one or more sets of spark gaps (series connected) which establish spark-over voltage, interrupt the flow of current, and prevent high current flow. The expulsion type has an arc-extinguishing chamber in series with the gaps to interrupt the power frequency current that flows after the gaps have been sparked over. Design refinements include using oxide film coated components and sealing the inner components in a chamber filled with an inert gas. Aluminum cells are used in some units.

c. Air terminals. Air terminals are used to intercept lightning discharges above facilities. Air terminals will be in accordance with Underwriters Laboratories, Inc. (UL) 96, UL Standard for Safety Lightning Protection Components, Fourth Edition (2000), and 96A, UL Standard for Safety Installation Requirements for Lightning Protection Systems, Tenth Edition (1998), NFPA 780, or MIL–HDBK-419A, Grounding, Bonding, and Shielding. Where building roof is not metal and building construction includes steel framing, air terminal connection assemblies are required.

d. Grounding. Grounding generally will conform to NFPA 780, unless otherwise specified. Guidance for grounding for purposes such as electromagnetic pulse (EMP), electromagnetic interference (EMI) shielding, and electronic facility grounding, are subjects of other engineering manuals that govern grounding requirements. Those grounding systems will also serve as grounding of the lightning protection system. Where separate systems are installed, such systems will be bonded below grade to any other independently installed exterior grounding system such as for EM shielding not suitable for complete lightning protection system. However, exterior protection grounding system will be bonded to static electricity exterior grounding system.

e. Ground rods. Ground rods are generally not less than ten feet in length, nor less than ¾-inch diameter pipe or equivalent solid rod. Rods are driven so that tops are at least six inches below finished grade, and three to eight feet beyond perimeter of building foundation. Where ground rods are used with a counterpoise, tops are driven to same elevation as counterpoise below finished grade. Contact with chemically injurious wastewater or other corrosive soils is avoided. Where avoidance of chemically injurious or corrosive soils is impracticable, stainless steel rod and magnesium anode protection is used. Where buried metal pipes enter a building, the nearest ground rod will be connected thereto.

f. Counterpoise. Each earth electrode subsystem or counterpoise consists of one or more closed loops or a grid arrangement of No. 1/0 AWG bare copper conductors installed around facility perimeter not less than two feet below earth surface. Larger conductors should be used when installed in highly corrosive soils. A second loop, if used, should not be less than ten feet beyond the first and inner loop. At least two ground rods are provided at each corner of each counterpoise loop where earth-seeking current tend to concentrate. Counterpoise will extend not less than three feet nor more than eight feet beyond the perimeter of building walls or footings.

g. Radial systems. A radial system of grounding consists of one or more No. 1/0 AWG copper conductors not less than 12 feet long, extending away from each ground rod or grounding connection. The use of multiple radials is an effective form of grounding, offering substantially lower reactance to the high frequency of lightning current wave fronts than do single straight conductors. Installation of grounding radials takes advantage of crags and cracks in surface rock formations in obtaining maximum available earth cover.

h. Structural components. Lightning protection is provided on the outside of exterior surfaces without reliance upon components of the building for conductors. Reinforcement steel may be used for down conductors in conformance with NFPA 780 and if approved by the using agency. Joints are made in no fewer than every fifth reinforcement rod and at corners of buildings. Joints are made electrically conductive and are connected top and bottom for connections to roof conductors and to grounding electrodes, respectively. Grounding pigtails from bottoms of reinforcement fabric are connected to exterior grounding system at same or lower elevation as that where pigtails leave walls and footings.

28-4. Lightning protection systems equipment requirements

All system components are made of copper, anodized aluminum, or stainless steel. Standard down conductors are usually large bare copper or aluminum stranded conductors that are constructed particularly for the lightning protection industry. A recent advancement is a coaxial cable that reduces the surge impedance as well as flashover. However, this cable is more costly than the conventional conductors. Interconnecting conductors are as important as other components. Tests in high-voltage laboratories demonstrate that a steep voltage wave front, such as created by lightning, causes the surge impedance in conventional conductors to increase to the point that side flashes occur. Installation of multiple grounding conductors for buildings and a roof grid system creating a faraday cage reduces the magnitude of current flow in any one conductor. However, side flashes can still occur.